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RESPONSES OF PROFUNDAL BENTHOS TO LAKES OF VARYING ACIDITIES

Report No 85-82-K

G.L. Vascotto
Supervising Biologist
Biological Research Section
Chemical Research Department

ABSTRACT

The hypolimnetic zone of 24 lakes spanning a surface pH of 4.5 to 8.2 in the Sudbury area of Ontario were sampled for zoobenthos. Non-acid lakes exhibited frequent severe oxygen depletion, pH surface-to-bottom ratios greater than unity, generally lower numbers of organisms, and taxa usually characteristic of oxygen stressed conditions. Acid lakes had typically oxygenated hypolimnia, pH surface-to-bottom ratios approaching unity, generally higher numbers of organisms, and some taxa characteristic of more oligotrophic conditions. Chironomus (Salinarius group) numbers were negatively related to pH and positively related to oxygen levels. Chaoborus punctipinnis was negatively related to dissolved oxygen, and Tanytarsus spl was negatively related to nitrates in acid lakes. Because of the strong influence of trophic related characteristics it was concluded that these organisms are not good acid indicators.

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740634-506-003	837.08	June 14, 1985	85-82-K

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EXECUTIVE SUMMARY

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As part of a study to attempt to determine whether the acidification history of lakes in Ontario can be successfully traced using the remains of selected organisms a series of investigations were undertaken. As a first step, attempts were made to develop an inference system based on the current distribution of diatoms, zooplankters, and profundal benthos to 24 lakes of varying pH. This document reports on the findings of the benthic component of these investigations.

In this study it was found that non-acid lakes frequently had anoxic hypolimnia, had pH surface to bottom ratios greater than unity, generally low numbers of organisms, and taxa reflecting oxygen stressed conditions. Acid lakes typically had well oxygenated hypolimnia, pH surface to bottom ratios close to unity, generally high numbers of organisms, and some taxa characteristic of more oligotrophic conditions. Two taxa were found to increase in numbers with increasing acidity; however, their occurrence and density were seriously affected by oxygen levels. No taxa abundances were found to decrease with increasing acidity.

The results of this study are quite different from other acid related benthic studies which generally report decreasing numbers with increasing acidity. This difference in results was attributed to the uniqueness of this study which dealt solely with the hypolimnetic zone, where the process of acidification may actually create a more hospitable environment by mimicking oligotrophic conditions. Although the existence of significant responses of organisms to pH change were demonstrated, these organisms are not deemed suitable as pH indicators because their abundances were also strongly influenced by the trophic characteristics of the hypolimnetic zone.

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To Mr. F.J. Kee
Director of Research

RESPONSES OF PROFUNDAL BENTHOS TO LAKES OF VARYING ACIDITIES

1.0 INTRODUCTION

Major changes observed in the biological components of lakes in portions of Ontario have been linked to acid precipitation. In lakes believed to have undergone acidification the indigenous fish species appear to have been the most adversely affected (Haines 1981, Harvey 1980). However, acidification of lakes has also been linked to dramatic changes, usually declines, in both number and species richness of phytoplankton, zooplankton, and benthos (Hendrey et al 1976, Almer et al 1974, 1978, Overrein et al 1980, Wiederholm and Eriksson 1980).

Historical data documenting actual changes in the pH and pH linked chemical parameters in Ontario lakes is sparse. Likewise the role played by geography, geology, and land use practices in governing the flora and fauna of the Laurentian Shield lakes is not well understood.

Ontario Hydro undertook a series of investigations to better understand the rate at which some lakes have undergone the acidification process. The intention has been to identify acidobiontic and acidophilous species of diatoms, cladocerans, and dipterans from 24 lakes of the Sudbury region, spanning a 4.5 to 8.2 surface pH range. By observing the distribution of these organisms' remains in dated lake sediment cores, it was hoped to reconstruct the recent pH history of the lakes.

The objectives of the study being reported here were to determine the present distribution of profundal zoobenthic taxa from the hypolimnetic zone of the 24 Sudbury Area lakes, relate the taxonomic distribution to the lake pH and/or metal content, and determine if indicator taxa are present and can be used for studying historical events.

It was considered desirable to investigate an environment which was seasonally relatively stable, so that any observed variability could be ascribed to relatively long-term, whole lake

changes, rather than responses to localized environmental perturbations. In lakes of this region it was felt that the hypolimnetic environment would meet the stability criteria, and the hypolimnetic benthos were chosen as the choice organisms because of their greater temporal stability and spatial homogeneity in taxonomic composition through the year as opposed to the littoral community (Vascotto, 1976).

2.0 MATERIALS AND METHODS

Twenty-four north-central Ontario lakes were selected for study and were sampled over one ten-day period in mid September 1980. (Figure 1). The sampling period was selected to coincide with the estimated period of maximum summer stagnation, preceding the fall turnover, and when most benthic insects were expected to be past the first or second instar. The lakes were selected on the basis of the following criteria:

- surface area between 50 and 250 ha
- maximum depth greater than 10 m
- lake set must cover a wide pH range
- lake set must cover a range of heavy metal levels
- lake set must be within 200 km of Sudbury

The lakes were selected from the Ontario Ministry of the Environment report (OMOE 1978) on lakes surveyed as part of the provincial Lake Acidification studies.

All samples were collected at the estimated maximum depth of the lake. Water samples for pH, alkalinity, and trace element analysis were collected near the bottom with a Van Dorn sampler, stored in acid-washed polyethylene bottles, and transported under cool, dark conditions to the field laboratory. Dissolved oxygen was determined by the modified Winkler method, with initial chemical additions carried out on site. pH determinations and total inflection point alkalinity titrations were carried out within 12 hours of collection according to the Ministry of Natural Resources procedures (OMNR 1980). The titration endpoint was calculated using the Gran transformation. Bottom temperatures were determined with an ISI probe. Trace element analysis was performed by the Analytical Services Section of Ontario Hydro. Details of the analytical methods and specific analytic results are presented in OHRDR 82-273-K, and OHRDR 82-309-K. For the multivariate analysis the chemical data was log transformed with the exception of pH.

Benthos was sampled in triplicate using a 900 cm^2 Ekman dredge. Samples were sieved with a 300 micron mesh net, and sorted using a dissecting microscope. Mounting, clearing and identification

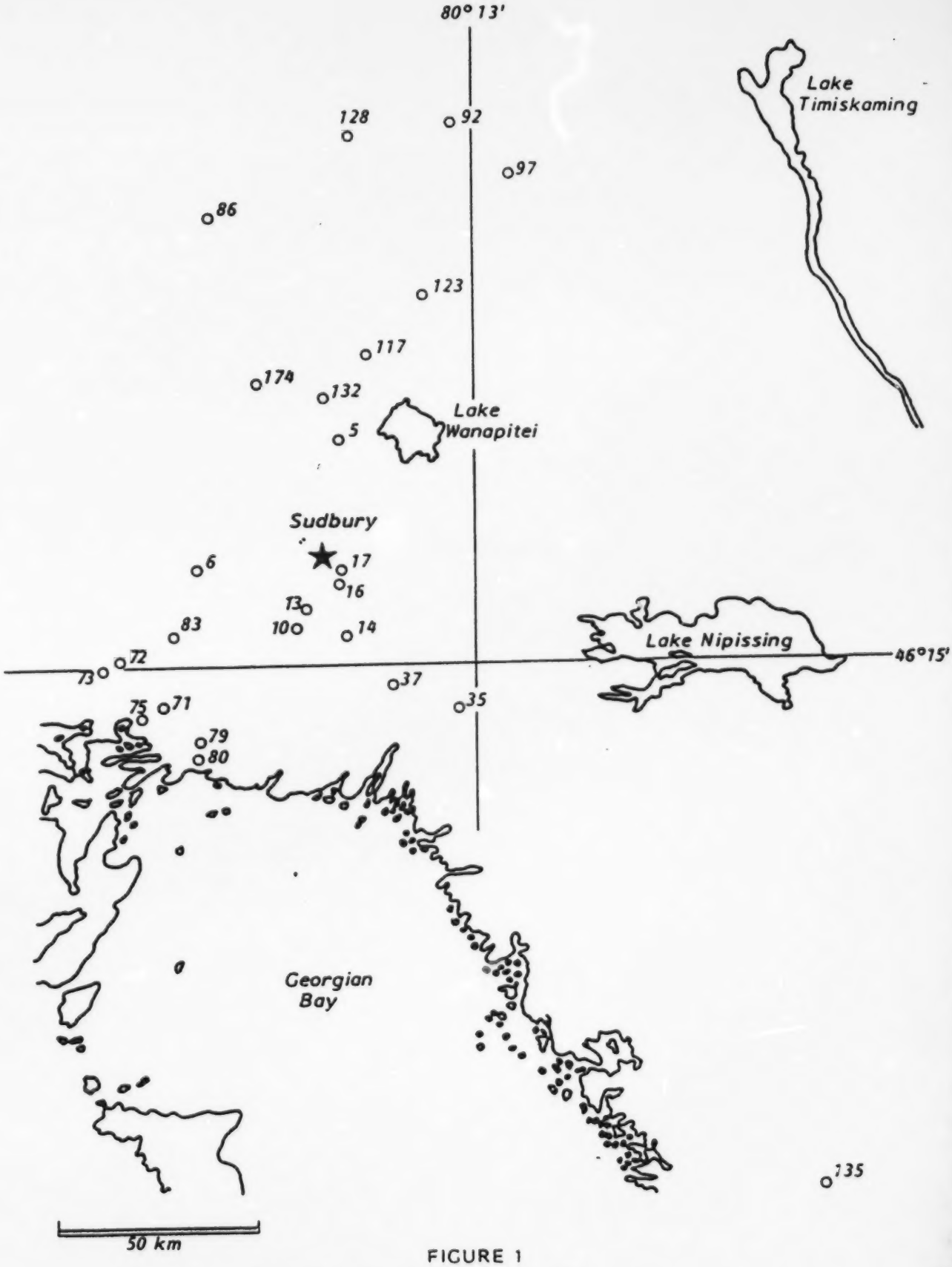

FIGURE 1

Geographic distribution of lakes sampled

TABLE 1

PHYSICAL CHARACTERISTICS OF THE LAKES SAMPLED

Lake	Lake No	Depth	Bot.pH	Mg/L			µg/L				Deg C
				Surf.pH	Calcium	Diss.02	Aluminum	Iron	Copper	Nickel	Temp
McKee	128	23	7.25	7.62	11.0	2.51	110	260	1.9	2	6.5
Elizabeth	72	24	7.15	7.65	10.0	0	30	3040	1.2	4	7.0
Frenchman	5	18	7.10	6.15	4.9	0	100	3040	5.9	21	6.0
Millerd	14	19	7.00	7.60	6.0	2.03	120	530	12.0	30	6.5
Skill	6	16	7.00	6.80	5.9	0	100	4370	4.7	9	7.0
McFarlane	17	16	6.99	7.55	15.4	1.87	30	60	7.8	104	9.5
Shoofly	86	29	6.95	8.27	36.1	0.65	30	60	3.7	5	5.0
Loon	73	20	6.85	7.42	6.3	0.91	50	520	2.5	6	7.0
Hutton	132	15	6.70	7.35	5.7	0	90	5790	1.8	6	6.0
Kakadiwaganda	37	20	6.50	7.40	5.7	4.40	70	360	5.1	17	6.0
Raft	16	14	6.40	7.30	5.1	3.60	30	160	7.5	83	10.0
Margaret	83	14	6.39	6.89	5.7	0.50	50	460	2.1	6	9.0
Leonard	135	14	6.35	5.85	2.7	0	50	1500	0.8	0.5	8.0
Helen	75	42	6.30	6.55	4.1	0.42	230	540	1.9	6	5.0
Lower Sturgeon	35	41	6.25	7.10	4.0	7.58	110	470	4.2	6	4.5
Michaud	174	23	6.00	5.50	3.9	0.08	100	450	2.2	6	5.5
Fraleck	117	13	5.55	6.00	3.9	2.33	180	120	1.6	5	8.0
Jim Edwards	97	20	5.30	5.20	2.3	3.60	240	20	0.5	4	12.0
George	80	41	5.25	5.40	2.9	3.42	240	170	5.3	10	6.0
Frederick	123	16	4.90	4.80	3.9	3.32	340	230	3.5	11	15.0
Sunnywater	92	37	4.90	4.90	2.4	4.39	310	30	1.1	4	8.5
OSA	79	40	4.85	4.70	2.9	4.34	300	60	5.3	11	8.0
Clearwater	13	18	4.72	4.57	2.8	2.68	230	120	22.8	82	9.0
Wavy	10	21	4.60	4.85	5.4	2.58	320	180	43.1	192	6.0

of each taxa were carried out by the Biological Identification Laboratory, following the keys of Saether(1970), Oliver et al (1978), and Hamilton (1965).

3.0 RESULTS

3.1 Physical Characteristics of the Lakes

The physical characteristics of the lakes sampled are summarized in Table 1. pH values ranged from 4.57 to 8.27 in surface waters, and 4.60 to 7.25 in bottom waters. Eight of the lakes had bottom waters of pH levels lower than 6.00. The ratio of surface pH to bottom pH tended to be greater than unity in more alkaline lakes and approached unity in lakes having pH lower than 6.0 (Figure 2).

Ni, Cu, and Zn are being mined in the Sudbury area, and the OMOE (1978) report suggested that Cu and Zn found in lake sediments were strongly correlated with distance from Sudbury. In this study the correlation coefficients between distance from assumed source and levels measured in the sediments were -0.665 and -0.883 respectively for the two metals. There was poor correlation between most metals levels and water pH, except for aluminum which had a correlation coefficient value of -0.804 and was significant at the 99% level. High aluminum levels have been linked to acid precipitation by a number of investigators and are believed to be usually the results of leaching from the watershed (Gjessing et al 1976, Wright and Gjessing 1976).

Although nutrients were not collected in this study, nutrient data covering the period 1974-1976 were available for these lakes in OMOE (1978). The results presented in the MOE report, coupled with the physical data collected in this study suggests that the lakes have similar trophic properties to those reported in the ELA study area by Brunskill et al (1971). That is, these lakes were generally low in nutrients, often displayed oxygen depletion near the bottom, and had low calcium and alkalinity.

At the time sampled most lakes displayed various stages of oxygen depletion in the hypolimnion; ten of the lakes had dissolved oxygen levels lower than 1 mg/L. From the data collected in this study it appeared that as a rule, acid lakes, that is lakes which exhibited pH levels lower than 6.0, were not anoxic in the hypolimnetic zone, having oxygen levels at the time of sampling between 2.3 and 4.4 mg/L. Non-acid lakes displayed a broader range of hypolimnetic oxygen levels, ranging between 7.5 and 0 mg/L, and appeared more likely to display severe oxygen depletion (Figure 3). Of the 14 non-acid lakes 5 had no measurable oxygen at the bottom and 9 had less than 2 mg/L of oxygen.

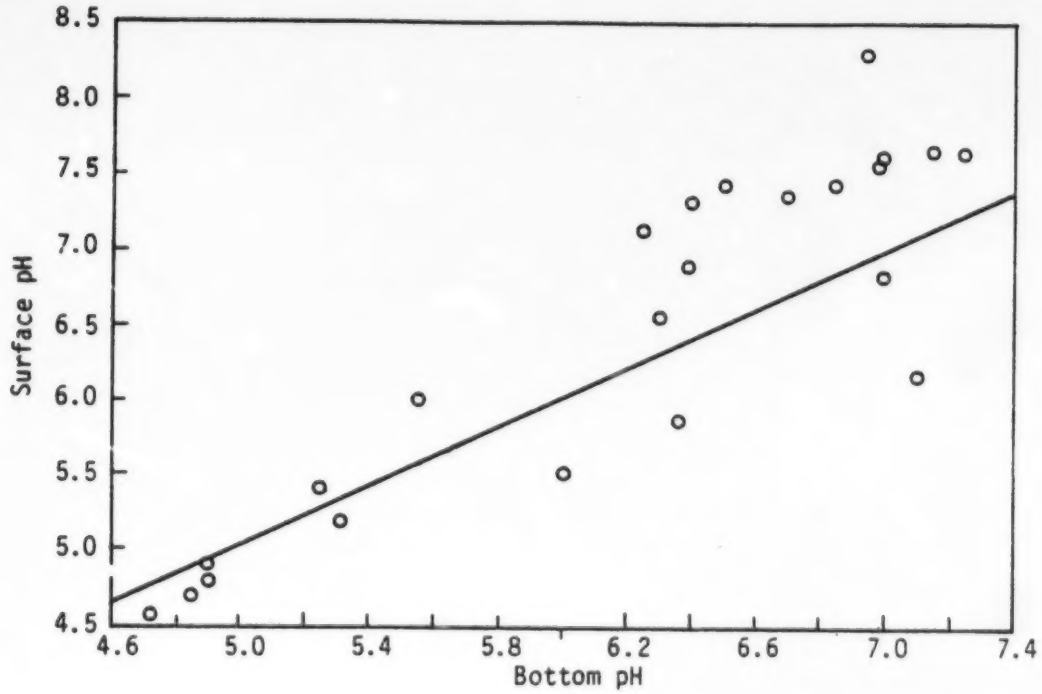

FIGURE 2

SURFACE VS BOTTOM pH

(Solid line represent 1:1 ratio of surface to bottom pH)

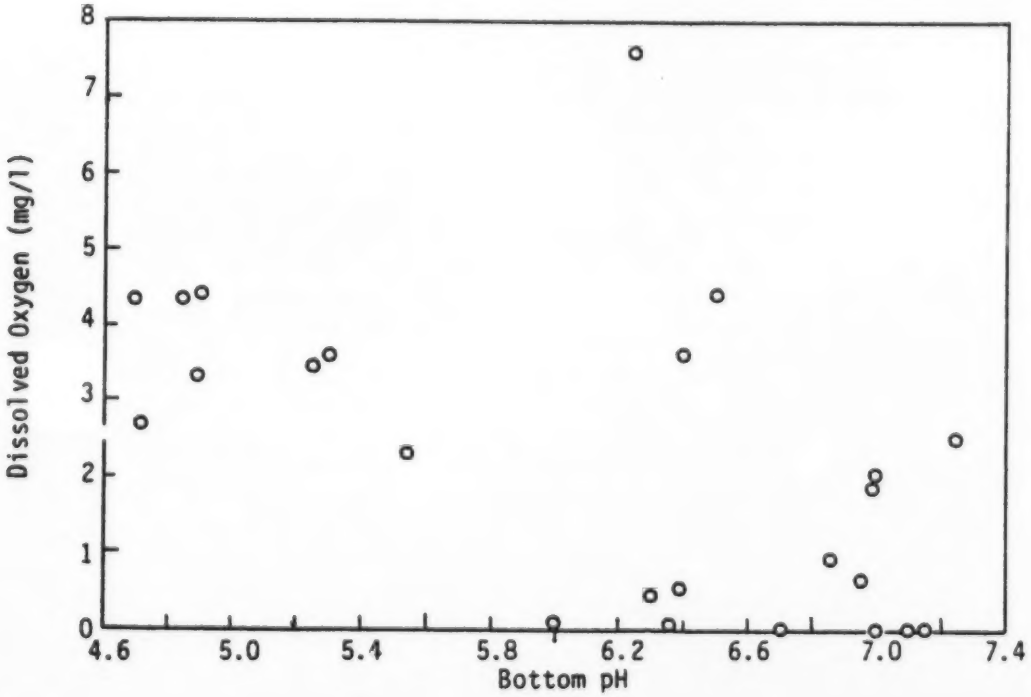

FIGURE 3

BOTTOM pH VS HYPOLIMNETIC OXYGEN LEVEL

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3.2 Lake Types

Given the wide ranges of oxygen levels, depths, temperature, and the other physical variables sampled, it was sought to try to group lakes based on the similarity of their physical characteristics.

The lakes were hierarchically ordered on the basis of information shared among lakes by the physical/chemical data collected using the Mutual Information statistic developed by Orloci (1968, 1969). The results are shown graphically in Figure 4. The vertical axis, I, represents the Mutual Information statistic level at which fusion of samples or groups shared the greatest similarity. The vertical distances between fusion points are relative and reflect the degree of similarity or difference. Along the horizontal axis, each vertical line represents one of the lakes sampled. As one moves vertically, each line is representative of the group of lakes fused beneath it. The higher the point at which two groups or samples merge the more dissimilar they can be expected to be. In most cases lakes were considered a group when at least one of the variables displayed no overlap in measured values.

The array of lake samples split itself into two large, quite dissimilar groups, A and B, which merged at the top of the dendogram. Group A was composed of samples from lakes having a pH higher than 6.35 and aluminum values lower than 110 g/L. Group B consisted of samples from pH lower than 6.35 and aluminum values greater than 110 µg/L (Figure 4). Other values differed between groups A and B, but in each case varying degrees of overlapping ranges were present. Clearly the acid linked characteristics of the data set overwhelmed any of the between lake differences in contributed by other variables. Therefore branch A was considered as representing non-acid lakes and B as representing acid ones.

The non-acid lakes were divided into two branches. Branch A could be further divided into branch I consisting of samples from four lakes with no measurable oxygen in the hypolimnion and iron values greater than 3000 µg/L, a highly reduced environment. The other branch II had some oxygen present and lower iron values (Figure 4). This branch had one odd lake having calcium concentrations greater than 36 mg/L, and is designated as group 3, and a group of seven lakes with calcium concentrations smaller than 16 mg/L (Group 2).

The acid lakes branch was also divided into two. One, B2, consisting of samples from two lakes, had pH values of 4.6 and 4.7, and separated primarily on elevated nickel and copper values (group

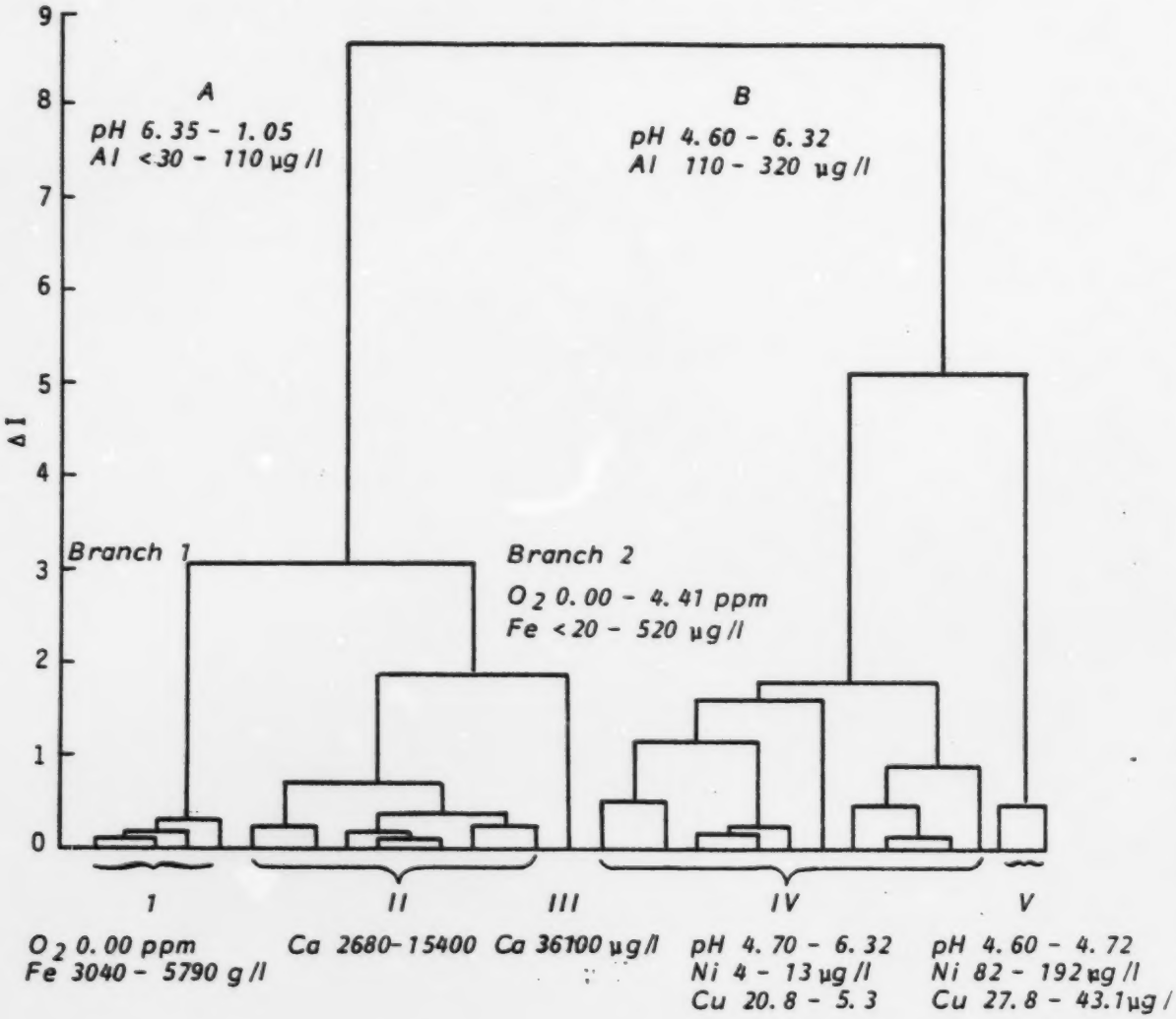

FIGURE 4

HIERARCHIAL ORDERING OF LAKES SAMPLED BASED ON PHYSICAL PARAMETERS

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V, Figure 4). The remainder of the acid lakes had pH values between 4.7 and 6.3, nickel values lower than 7 mg/L, copper values lower than 6 mg/L, and oxygen levels between 0.08 and 7.58 mg/L.

From the results of this analysis it was concluded that although the hypolimnion reflected a wide range of acid conditions, other factors linked to trophic lake typologies were also present throughout the lake set, particularly in the non-acid lake set, which probably had considerable impact on the composition of the benthic fauna.

The geographic distribution of the groups is illustrated in Figure 5. Group V (acid and high metals) was the only group found exclusively in the vicinity of Sudbury, the SO_2 source often implicated in lake acidification in the region. The other acid group of lakes, group IV was principally found at the north-south extremes of an axis whose origin was in the Killarney area in the northernmost part of Georgian Bay, and west north-west of Lake Wanapitei. Most of the other lakes sampled within a 50 km radius of Sudbury were classified as non-acid lakes from groups I and II, and some of the lakes from group II were the closest lakes to Sudbury that were sampled.

3.3 Biological Characteristics of the Lakes

The benthic collection yielded 25 taxa (Table 2). A single amphipod (Pontoporeia affinis) was collected in one lake, Lower Sturgeon, at a pH of 5.9. No mollusks were collected; 30 oligochaete specimens were found consisting of Limnodrilus hoffmeisteri and young unidentified tubificids. The rest of the collections were exclusively composed of members of the Diptera. Both number of taxa and total number of organisms collected appear to increase with decreasing pH (Table 2 and Figure 6).

The dipterans collected seemed quite typical for the region consisting primarily of the genera Chaoborus, Phaenopsectra, Chironomus, Tanytarsus, Procladius, Protanypus, and Psectrocladius. For hypolimnetic samples it is generally accepted that Chaoborus is often found in acid stressed lakes, while Phaenopsectra, the species of Chironomus here reported, and the usually predatory Procladius, typifies profundal zones which are characteristically mesotrophic to eutrophic in character. The presence of Tanytarsus, Protanypus, and members of the Orthocladiinae are considered as inhabiting well oxygenated waters of lakes exhibiting more oligotrophic characteristics (Brinkhurst 1974, Brundin 1949).

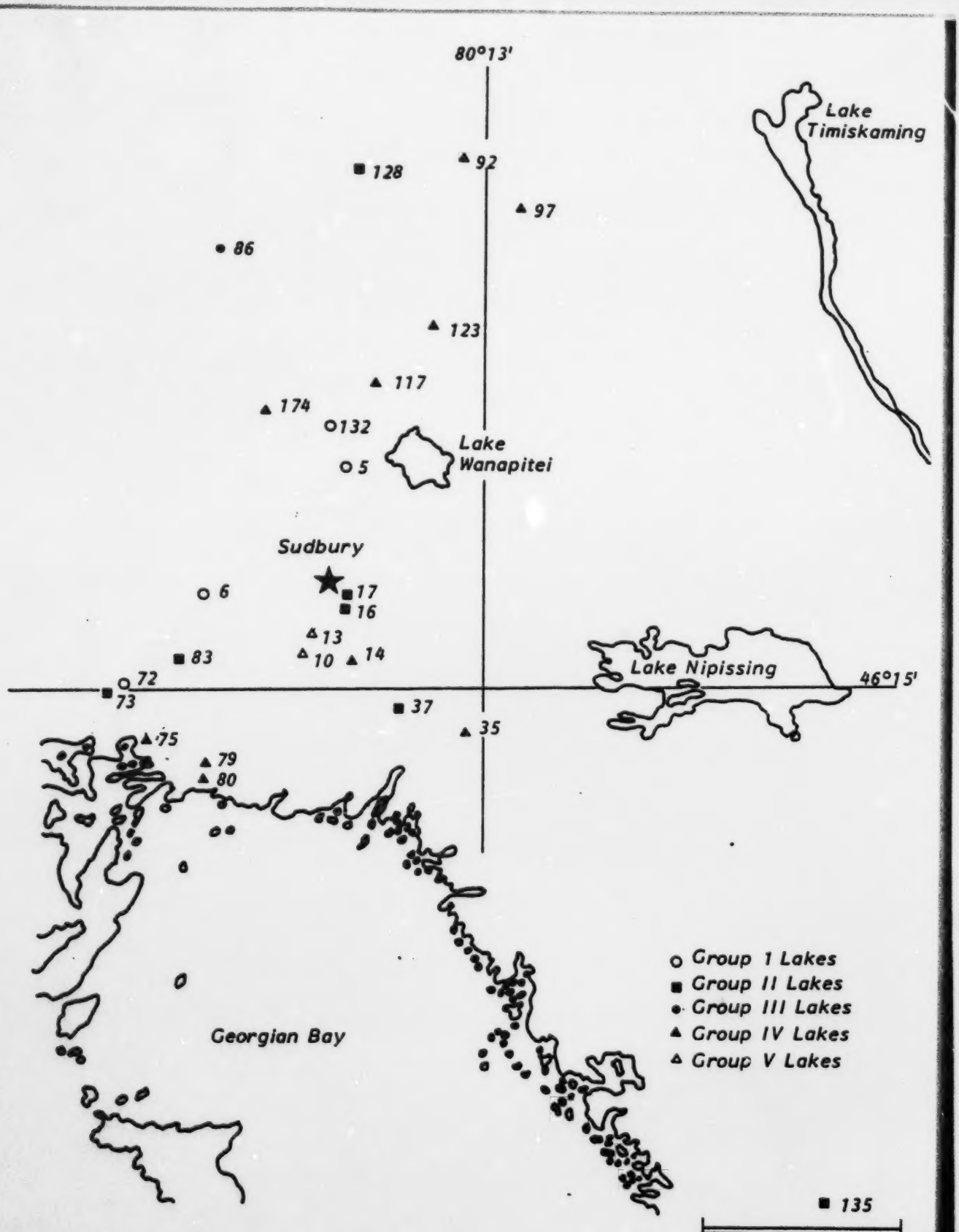

FIGURE 5

GEOGRAPHIC DISTRIBUTION OF THE LAKE GROUPS

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TABLE 3

THE OCCURRENCE OF TAXA (X) RELATIVE TO HYDROGEN ION pH IN THE LAKES SAMPLED

SAMPLE	DEPTH	pH	A. blasesmyia	C. punctipinnis	C. flavicans	C. Salinarius	C. Fluviosus	C. Thummi	Cryptodentipes sp 2	Einfeldia sp	Heterotrissocladius sp	Heterotrissocladius cf	Phaenopsectra sp	Procladius sp	Protanypus sp1	Protanypus sp	Psectrocladius T2	Psectrocladd. T8	Tanytarsus sp1	P. affinis	Ceratopogonidae	Tubificidae	Sialis
McKee	23	7.2				X							X	X							X	X	
Elizabeth	24	7.1		X																		X	
Frenchman	18	7.1																					
Millerd	19	7.0	X	X	X								X	X									
Skill	16	7.0	X																				
McFarlane	16	6.9	X	X	X																		
Shoofly	29	6.9																					
Loon	20	6.8		X																		X	
Hutton	15	6.7		X	X																		
Kakakiwaganda	20	6.5				X							X	X									
Raft	14	6.4		X	X	X							X										
Margaret	14	6.3		X	X		X																
Leonard	14	6.3		X						X			X									X	
Helen	42	6.3				X						X	X	X				X	X				
Lower Sturgeon	41	6.2				X														X		X	
Michaud	23	6.0		X									X						X				
Fraleck	13	5.5		X		X							X						X				
Jim Edwards	20	5.3				X		X		X	X	X	X	X					X			X	
George	41	5.2				X							X			X						X	
Frederick	16	4.9		X					X		X		X	X	X	X	X	X	X			X	X
Sunnywater	37	4.9																					
63A	40	4.8		X		X							X									X	
Clearwater	18	4.7		X		x		x					x					x	x				
Navy	21	4.6	X	X		X							X			X							

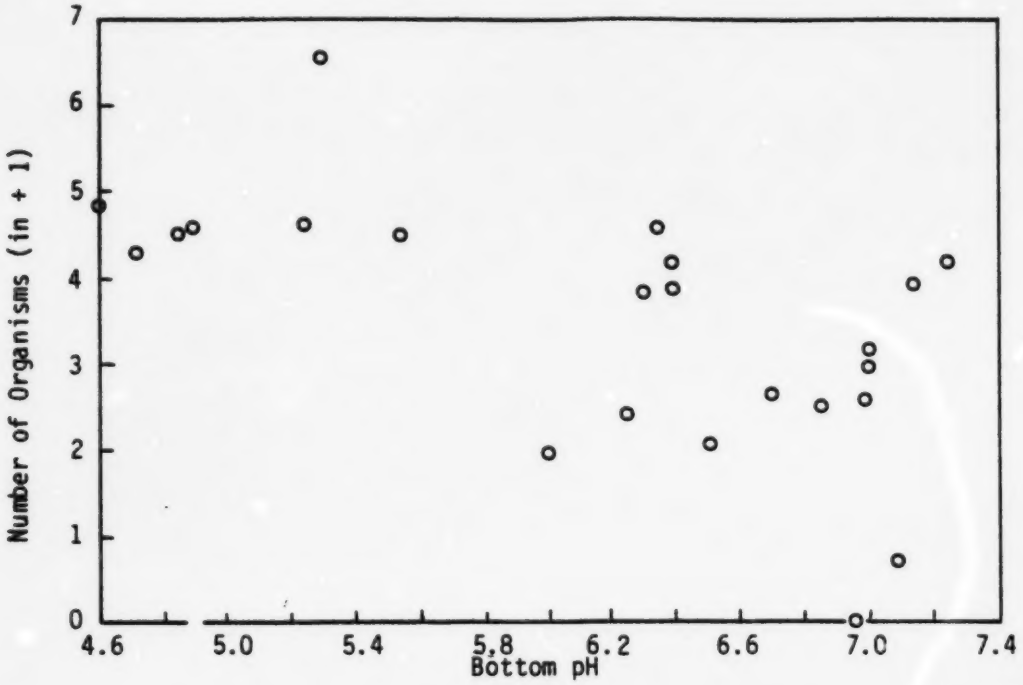
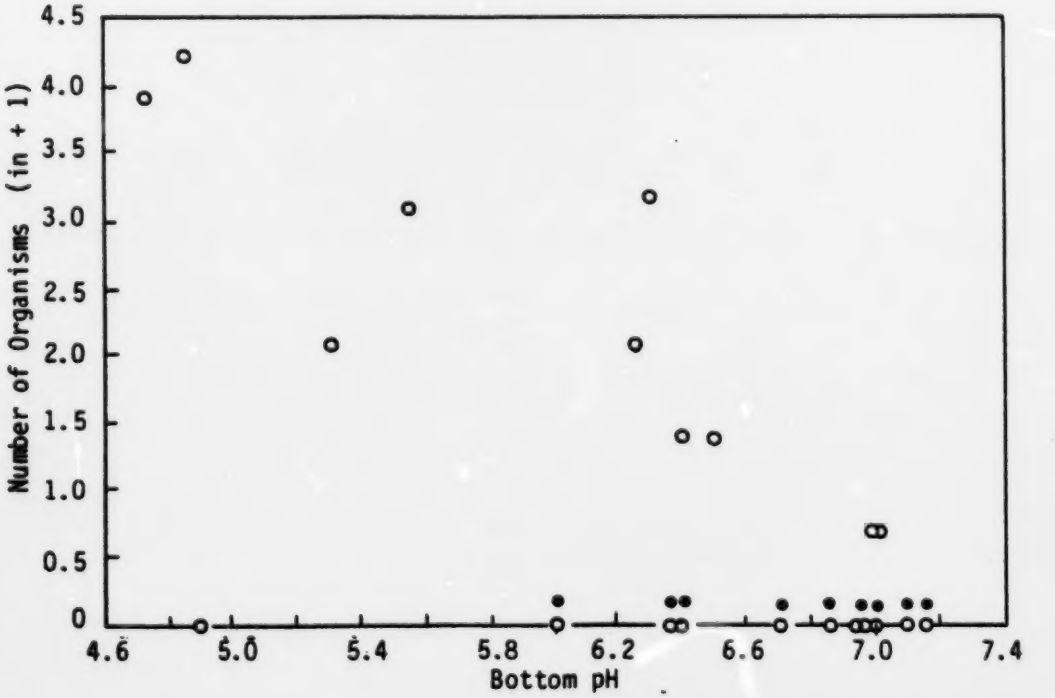


FIGURE 6

TOTAL NUMBER OF ORGANISMS PER SAMPLE VS pH



● *Indicates samples having dissolved oxygen <1 ppm*

FIGURE 7

NUMBERS OF C.(SALINARIUS grp) VS pH

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The species-poor lakes tended to be the high pH lakes having anoxic conditions in the hypolimnion. These characteristics were reflected in the taxonomic composition of the samples which were heavily dominated by the two Chaoborus taxa, and the absence of more oligotrophic indicators such as Heterotrissocladius, Protanypus, Tanytarsus, and the usually epilimnetic taxon Psectrocladius (Table 2), all of which are common in shield-type lakes of Central Canada.

The number of benthic organisms collected did not appear unusual for the time of the year or the region. The unique biotic characteristics of the samples were the virtual absence of Pontoporeia affinis in oxygenated lakes, the complete absence of sphaeriids, and the relative paucity in numbers and taxa of oligochaetes. These are in complete contrast to the findings in the ELA area by Hamilton (1971), and Vascotto (1976), for lakes having similar physical characteristics.

3.4 Relationships Between Lake Type and Benthos

The major visible difference in biological composition between acid and non-acid lakes was found among the two species of Chaoborus. C. punctipinnis was found in all groups of lakes, and was the numerically dominant feature of the non-acid ones, particularly group I. C. flavicans was found only in five non-acid lakes, never occurring at pH lower than 6.3. It was not a very abundant taxon and occurred in only five of the non-acid lakes.

The acid lakes were characterized by a more diverse benthic fauna strongly dominated by members of Chironomus and Phaenopsectra, and the presence of taxa which are generally considered as oligotrophic indicators. Group V samples, the high metals pair of lakes, did not appear very different from the group IV samples.

An attempt was made to detect correlations between the number of individuals of the most numerically dominant taxa collected (C. punctipinnis, C. flavicans, Chironomus (Salinarius group), Phaenopsectra sp, and Tanytarsus spl), and the physical variables listed in Table 1 plus nitrates and total phosphorus. Only correlation values having a significance value greater than 0.05 were accepted.

The only significant correlations encountered were:

C. punctipinnis - inversely correlated to depth ($r = -0.702$) and oxygen ($r = -0.4821$)

C. (Salinarius group) - correlated to aluminum ($r = -0.610$), nitrates ($r = 0.589$), and inversely to pH ($r = -0.600$)

Phaenopsectra spp - positively related to aluminum (r = -0.543), and oxygen (r = 0.488), and negatively related to pH (r = -0.524)

The increase in numbers of C. (Salinarius group) with decreasing pH is particularly significant (r = -0.999) for samples having dissolved oxygen levels greater than 1 mg/L) when one considers that the taxon was never found in lakes having less than 1 mg/L dissolved oxygen (9 cases), and was only absent from two lakes having dissolved oxygen levels greater than 1 mg/L (Figure 7). The relationships between numbers, oxygen and pH were not quite as striking in the other two taxa.

The analysis was repeated for the two branches (acid and non-acid) of lake groups. The results of the analysis are summarized in Table 3. Among the non-acid lakes C. punctipinnis was negatively related to aluminum concentrations, and C. (Salinarius group) was positively related to dissolved oxygen. In the acid lakes C. punctipinnis was negatively correlated with depth, and Tanytarsus spl was negatively correlated to depth and nitrates. The latter was interpreted as indicating trophic conditions in the hypolimnion.

The results of these analyses strongly suggest that the factors which most strongly influence the numerical abundance of individual taxa in the hypolimnetic sediments of the overall lake set are those related to the trophic state of the lakes such as depth and nitrates, while the ubiquitous taxon C. (Salinarius group) was also strongly influenced by pH. In non-acid lakes the limiting role of low dissolved oxygen most strongly influenced the distribution of Chironomus, and overwhelmed the influence of any other variable measured. C. punctipinnis, on the other hand, was negatively related to the pH linked aluminum. Within the acid lake set no influence of pH on the numbers of individual taxa was evident, depth and nitrate levels being the only significant relationships found. Depth was negatively related to C. punctipinnis abundance, and nitrates negatively related to the abundance of Tanytarsus spl, a taxon usually inhabitating the hypolimnion of oligotrophic lakes.

4.0 DISCUSSION

Based on the available literature it was anticipated that a clear trend of decreasing numerical and taxonomic abundance would be apparent with increasing acidification (Raddum 1978, 1980). Mollusks and amphipods would decrease with increasing acidification, and ultimately disappear (Hendrey et al 1976; Okland and Okland 1980; Raddum 1978; Raddum and Saether 1981), and major

TABLE 3

Correlation coefficients between the major benthic taxa collected and selected variables. a) non-acid lakes (n=12), and b) acid lakes (n=12). r values significant at the 0.95 level are underlined.

a) Non-acid (n=12)

	Depth	NO_3	Al	D.O.	pH
C. punctipinnis	-0.5256	-0.4733	-0.6693	-0.6082	-0.2001
C. flavicans	-0.5974	-0.4716	-0.1646	0.1697	-0.3204
C. salinarius	0.1667	0.3621	0.1565	0.9068	0.2264
Phaenopsectra (spp)	0.0842	0.3995	-0.2572	0.5820	-0.0091
Tanytarsus sp.	0.4622	0.1731	0.4506	0.3270	0.5058

b) Acid (n=12)

C. punctipinnis	-0.7700	0.0310	0.1519	-0.1262	-0.3191
C. flavicans	-	-	-	-	-
C. salinarius	0.3062	0.4493	0.2926	-0.4096	-0.1775
Phaenopsectra (spp)	0.0068	-0.3938	-0.1104	0.1239	0.0304
Tanytarsus sp.	-0.7120	-0.7009	-0.0578	-0.1714	0.0714

shifts in taxonomic composition of the major profundal benthic groups relative to pH could be demonstrated. Such trends have been demonstrated to a certain extent for selected taxa in European lakes (Okland and Okland 1980).

In this study the paucity or absence of mollusks and crustaceans conforms with the findings reported by others (Okland & Okland, 1980). However, the other assumptions related to abundance did not materialize; in fact the trends, albeit weak, were of increasing taxonomic and overall numerical abundance with decreasing pH, and within taxa there was no evidence of decreasing abundance with increasing acidification, but the opposite clearly occurred. This discrepancy between this study and the literature can most likely be attributed to the fact that most benthic acid related studies reported are either specific to littoral and sublittoral sampling, or do not differentiate between samples from epilimnetic and hypolimnetic habitats, eg, (Raddum 1980; Okland et al 1980; Roff and Kwiatkowski 1977).

The importance of differentiating between epilimnetic and hypolimnetic benthic collections cannot be over-emphasized. It has long been demonstrated that even in undisturbed systems species diversity, taxonomic composition, and numerical abundance change with water depth (Lundbeck 1926), and relative to the thermocline (Vascotto 1976). The limiting factors in the two environments tend to be considerably different. Suitable substrate, presence or absence of epiphytes and vegetation, shelter from wave action, and temperature are important in the hypolimnetic zone, while presence of oxygen is the overwhelming variable in the hypolimnion. The hypothesis presented is that although the expected trends of benthos among lakes of differing acidities were not fully realized it is postulated that acidification alters the trophic characteristics of hypolimnetic portions of lakes, which in turn have a significant influence on the fauna found there. These observed changes will be rationalized in terms of the surface-to-bottom differential in measured pH, and in terms of oxygen content of acid vs non-acid lakes.

The decreasing differences in pH between surface and bottom waters with increasing acidity are probably quite important in the differential impact between epilimnetic and hypolimnetic organisms in lakes. There is usually a decline of pH with depth in lakes displaying clinograde oxygen curve during the summer (G.E. Hutchinson, 1957). In non-acidified lakes the difference between top and bottom can be as much as one pH unit, depending on the time of the year, as was evident in two Laurentian Shield lakes sampled in 1970 (Vascotto, 1976). In the lakes investigated in this study there was considerable variation between surface and bottom pH at low acidities, but below a surface pH of

6.0 virtually no difference between surface and bottom was evident (Figure 2). Kelso reported (Kelso et al 1981), that the pH of interstitial waters did not decrease below a pH of 5.3 even in waters having pH's as low as 4.8 . Since surface pH's of 5.75 to 7.0 are common in the Shield, as shown in the ELA surveys (Brunskill et al, 1971), and the Ontario Ministry of the Environment Survey (MOE 1978), then it appears probable that in many Laurentian Shield lakes the profundal benthos normally occupy habitats considerably more acid than the epilimnetic zone, and therefore would be exposed to considerably less acid induced stresses than their epilimnetic counterparts during acidification. It seems likely that the hypolimnetic benthos does not become directly influenced by an acid stress until surface pH's drop below 6.0. An exception would be semi-planktonic early instars, and possibly some of the diurnal migrants, such as Chaoborus, which normally execute vertical migrations in the water column.

The hypolimnia of the acid portion of the 24 lakes were generally better oxygenated than the non-acid ones. This is consistent with the concept that the process of acidification is a process of oligotrophication, which in turn has sparked fears of lakes becoming barren, and non productive. This concept has come under some scrutiny during the last five years. For example, Schindler (1980) reported on the experimental acidification of a lake . Having lowered the pH by approximately one pH unit, to 5.6, no evidence of oligotrophication was found, but the possibility of oligotrophication at lower pH's was not ruled out. Dickson (1980), on the other hand, observed not only significant increases in transparency, but also lower than average phosphorus levels in acidified Swedish lakes. Suggestions that acidification reduces primary production have been presented but the evidence is inconsistent. Earlier studies suggested decreased productivity (Roff and Kwiatkowski, 1977), while later studies suggested no difference (Schindler et al, 1980; Dillon et al, 1979). Although there is some question as to whether wholesale oligotrophication takes place during acidification, there is little question that some oligotrophic characteristics manifest themselves in acid lakes. It is probable that this phenomenon of increased oxygen levels, which is a characteristic of oligotrophic hypolimnia, is present in these acid lakes, and it is probably acid driven.

Inhibition of microbial activity in the sediment of acid lakes, and reduction in microbial numbers with lowering pH have been documented (Traaen, 1980; Francis et al 1984). Experimental data has shown that oxygen utilization at sediment surface is reduced, and phosphorus release from the sediment is also reduced under acid conditions (Laake, 1976). These conditions probably explain the higher oxygen conditions observed in acid hypolimnia.

Profundal benthic organisms are adapted to an environment which is relatively temporally stable and often oxygen limited. The responses of the benthic fauna to oxygen minima have made them useful indicators of the trophic level of the lakes studied, and have been widely used as such (Thienemann, 1928; Berg, 1938; Brundin, 1949; and Saether, 1979).

It is proposed that a direct result of the acidification process has been of the creation of hypolimnetic oxygen conditions which closely mimic the oligotrophic hypolimnia, and that this is reflected in the fauna found. The trend of seemingly increasing numbers of organisms and taxa, the appearance of Tanitarsini and Orthocladini with decreasing pH all support this premise. The numerically dominant species of Chironomus found in the samples, although tolerant of relatively low oxygen waters, were unable to tolerate dissolved oxygen levels lower than 1 mg/L, but were found primarily in acid low waters and appear to represent a true acidophobic taxon. However, it is not very clear to what extent the observed response was directly due to, decreases in pH or the concomittant increase in dissolved oxygen.

Of special interest was the seemingly peculiar distribution of the two species of Chaoborus, C. flavicans and C. punctipinnis. C. flavicans was only found in lakes having pH's greater than 6.2, while C. punctipinnis was found throughout the range of lakes, and its abundance was inversely correlated with oxygen. A review of the North American published literature revealed no description of C. flavicans from stratified lakes of pH's lower than 6.3. The European literature, however, has several references to the species occurring under acid conditions (Hongve 1975, Raddum 1978). Whether the distribution of Chaoborus found in this study is an artifact of a limited sample size or reflects differences in pH tolerance between the North American and European types is not known. Except for the mollusks and crustaceans, the Chaoboridae is probably the group that one would most likely expect to display a direct acid reaction. At surface pH's above 6.0 the animals presumably would have daily relief from the low interstitial pH by means of their diurnal vertical migrations; below a surface pH of 6.0, they would be exposed to continuous lower pH. Verification of this hypothesis may warrant further study.

5.0 CONCLUSIONS

The results obtained in these investigations exemplify the difficulties that are often encountered in field studies when a direct linkage between a physical variable and biological response are sought by assuming simple responses in a complex ecosystem; for example, benthos vs pH. It had been generally accepted that both

numerical and taxonomic abundance decrease with decreasing pH, but in this study the reverse seemed to take place. The abundances of specific taxa, and number of taxa were found to increase with acidity. This phenomenon was particularly true for C. salinarius, and to a lesser extent Phaenopsectra spp; however, these two taxa are of limited use as acid indicators because much of the observed response was related to availability of oxygen in the hypolimnion.

It was also found that most oxygenated hypolimnia were found among the acid lakes. It was concluded that acid conditions favored the creation of oxygenated hypolimnia, and these in turn influenced the fauna found there. And the changes to the hypolimnion brought about by acidification to the oxygen and associated variables there had a greater influence on the benthic fauna than the pH itself.

It was also rationalized that the sediment water interface tended to be acid under most conditions, and did not change as the overlying water became acidified; thus the hypolimnetic benthos are likely to be more acid tolerant than their epilimnetic counterparts, and are not likely to be stressed directly by acidification until very low pH levels.

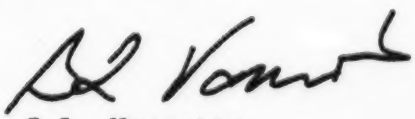
Based on the above it is concluded that profundal benthic organisms are not likely to be the best indicators of acidity, particularly since the variables which limit the distribution of most profundal species can either reflect trophic conditions of the lakes, or as in this study, the effects of acidity.

The two species of the genus Chaoborus may be useful acid indicators, but this conclusion would have to be verified by further investigations.

Approved by:

O.A. Kupcis
Manager
Chemical Research Department

Prepared by:



G.L. Vascotto
Supervising Biologist
Biological Research Section

GLV:rv

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